The Near Infrared Camera and Multi-Object Spectrometer Cooling System

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ABSTRACT

NASA is developing the NICMOS Cooling System (NCS) for deployment during Servicing Mission 3 (SM3) of the Hubble Space Telescope (HST) in late 1999. The NCS is intended to provide mechanical cryocooling for the Near Infrared Camera and Multi-Object Spectrometer (NICMOS) instrument that was installed during Servicing Mission 2 in February 1997. The NICMOS with NCS can potentially continue the near-IR capability of HST through the currently scheduled end-of-mission in 2010. The NCS hardware is currently in final integration and will soon start a series of rigorous ground and flight tests that will prepare it for installation in the HST.

Keywords: cryocooler, HST

1. INTRODUCTION

The NICMOS instrument provides the HST with near-infrared imaging and limited spectrographic capabilities in the 800 nm to 2.5 μm wavelength range. As originally designed, the instrument uses solid N_2 cryogen to maintain the detectors at ~ 58 K for up to 4.5 years.

A post-launch thermal short developed in the forward end of the cryostat with two major effects. First, the focus of Camera 3 (the widest field, optically slowest camera) is shifted beyond the range of the internal focus adjustment mechanism. Secondly, the increased heat loading has shortened the lifetime of the cryogen. With the current heat load, cryogen depletion is expected in January 1999.

In response to the focus problem, the HST Program has already executed some campaign-mode observations with Camera 3 (early January 1998). These observations used the HST secondary mirror to compensate for the internal focus shift. The results will soon be released, but preliminary analyses show that Camera 3 is working superbly after being brought into focus.

Also in anticipation of the shortened lifetime, NASA and the Space Telescope Science Institute are adjusting HST scheduling so that 40 to 50% of the available time will be used for NICMOS observations. An additional Call for Proposals was completed in 1997 to support this scheduling activity. As a result, we expect that more than half of the originally planned NICMOS observations will be completed before cryogen depletion.

Recognizing the importance of HST's near-IR capability, NASA also started development of a lifetime-extending cooling system as a technology demonstration effort. The NCS will use the excess power capability of the HST to provide continued scientific operation of the NICMOS instrument past cryogen depletion. The NCS has been regularly reviewed by science, technology, and engineering panels, all of which have endorsed and supported its continued development. The final decision to fly the NCS on HST SM3 is pending a scientific review of its status in early 1999. This paper summarizes the NCS development effort since its inception in April 1997.

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2. CHALLENGES

NCS development faces several unique challenges. Each of these must be overcome to ensure a scientifically viable deployment in 1999.

- The technology is new and has not been used in space before. It has, however, been used reliably in ground-based applications.
- The time from program start to flight is very short. Success depends heavily on being able to bring the most experienced groups across diverse engineering disciplines to build and test the NCS flight hardware.
- The NICMOS is already in orbit and is not available for testing. In addition to the usual problems on validating on-orbit servicing procedures, we must also understand the detailed status of the NICMOS instrument. In particular, we must ensure that the parasitic heat loads on the NCS are within the capabilities of the system.

2.1. Technological Readiness

The heart of the NCS is the mechanical cryocooler. We selected the reverse-Brayton cycle turbine cooler developed by Creare, Inc. for two major reasons.

We require a fairly large cooling power due to the characteristics of the existing NICMOS cryogenic interfaces. The delivered cooling power to the cryostat is $\sim$ 400 mW at 70 K. However, the total loading on the cooler is $\sim$ 8 W. The bulk of this cooling power is needed to overcome the parasitic losses in the lines connecting to the inside of the cryostat. We have baselined a 11 W capability for the NCS, including margin, which the Creare design can meet.

The HST is also very demanding when it comes to mechanical disturbances. The observatory routinely maintains a 3 milliarcsec pointing stability. This would be difficult if on-board subsystems produced a significant amount of vibration. Here again, the Creare high-speed turbine design (7500 Hz rotation rate) minimizes the possibility of pointing disturbances.

Because this technology has not been flown before, NASA will be flying the NCS components on a 10-day Space Shuttle test flight (STS-95, the Hubble Orbital System Test or HOST mission) in late 1998. By combining a rigorous ground testing program with a confirming flight test, we will better ensure that NCS will operate as expected in the HST.

The Project team has also organized several reviews of this project by independent technical and scientific experts. These reviews have been extremely helpful in pointing out past mistakes and highlighting areas where special care may be prudent. Such advice is an indispensible ingredient for success, especially with the short development time available to us.

2.2. Development Time

Less than a year has passed since we started discussing the concept for the NCS. During this time, significant technical progress has been made, as well as numerous programmatic discussions (for the first six months, we averaged at least one formal NCS presentation per month).

In order to accommodate both the SM3 flight readiness schedule and the HOST flight, the hardware must be complete by mid-1998. This is less than 14 months from project start. It is fortunate that Creare had already been actively developing the cooler for other agencies and applications. By the time the NCS development started, they were well under way to developing a space-borne system.

To reduce the development time, the HST Project has brought other project resources to bear. The Creare team is concentrating on developing the cooler and related cryo-machinery. Flight electronics, mechanical packaging, supporting systems, and the heat rejection radiator are handled by other organizations on the HST Team. The integration and final testing of all components is being done at the NASA Goddard Space Flight Center. This division of labor brings to bear the best HST experience and technical capabilities available, and is a requirement for success in such a fast track program.

2.3. Testing for On-Orbit Servicing

On-orbit servicing poses some interesting challenges. In large part, this arises because it is an extension of the traditional ground-based integration and testing activities, yet it occurs in a highly constrained and hazardous environment. Success depends heavily on careful planning and practice, particularly in the areas of astronaut training, tooling, and familiarization.

The HST project has developed a set of simulators that have already proven their value for the initial deployment and two servicing missions. These devices are used to simulate, as closely as possible, the on-orbit experience on the ground so that we can develop detailed operational procedures. High fidelity mechanical and electrical models take the place of the real HST during ground validation to keep on-orbit surprises to a minimum.

This same philosophy has been applied to the NCS test program. In this case, mechanical fit and electrical function is not sufficient. We must ensure that the thermal characteristics of the NICMOS are well understood, and that they are compatible with the NCS design. To this end, we have constructed a NICMOS Cooling Loop Simulator (NCLS). This device uses the same parts, design, and fabrication procedures as the actual NICMOS loop. It does not include a cryostat since that would be too costly. However, the NCLS imitates the NICMOS parasitics and flow impedances in detail. It will be fully characterized in a vacuum chamber so that the thermal models are validated, and also to serve as a surrogate for the NICMOS during testing.

3. THE NCS SYSTEM

Figure 1 shows a block diagram of the NCS. It consists of three major subsystems; the cryocooler which provides the mechanical cooling, the Capillary Pumped Loop (CPL) which moves heat from the cryocooler to an external radiator, and the circulator loop which moves heat from inside the NICMOS to the cryocooler heat exchanger.

The cryocooler is a reverse-Brayton cycle machine. In the process of producing cooling, it dissipates heat (from 250 W to 450 W, depending on the operating mode) which is carried away by a two-phase ammonia CPL to an external radiator. The cold end of the cryocooler is attached to a heat exchanger which cools the Neon gas in a circulation loop that is attached to the NICMOS. A pump circulates the gas in this loop to transfer the heat from the NICMOS to the cryocooler. Flexible lines form the astronaut interface to the NICMOS. These lines terminate in

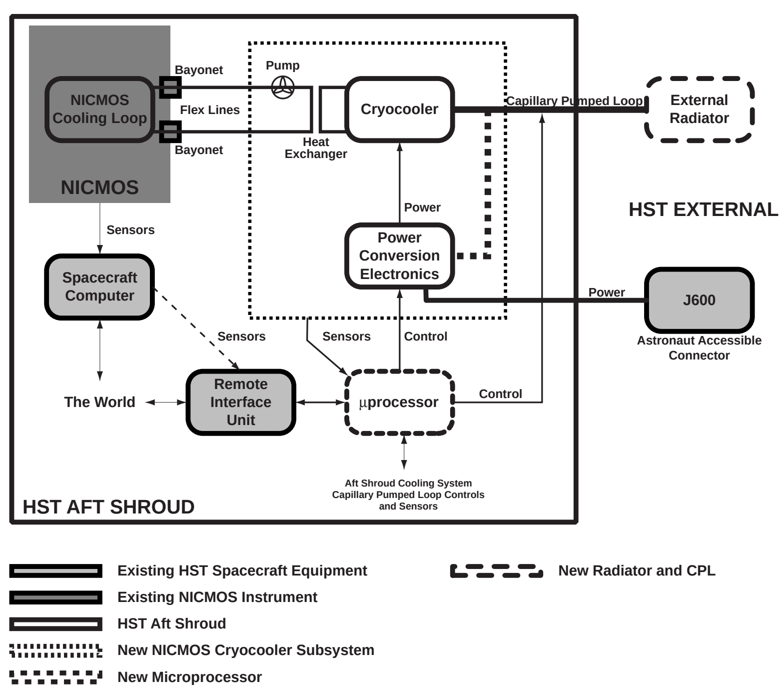

Figure 1. This figure shows a block diagram of the NCS. See text for description.

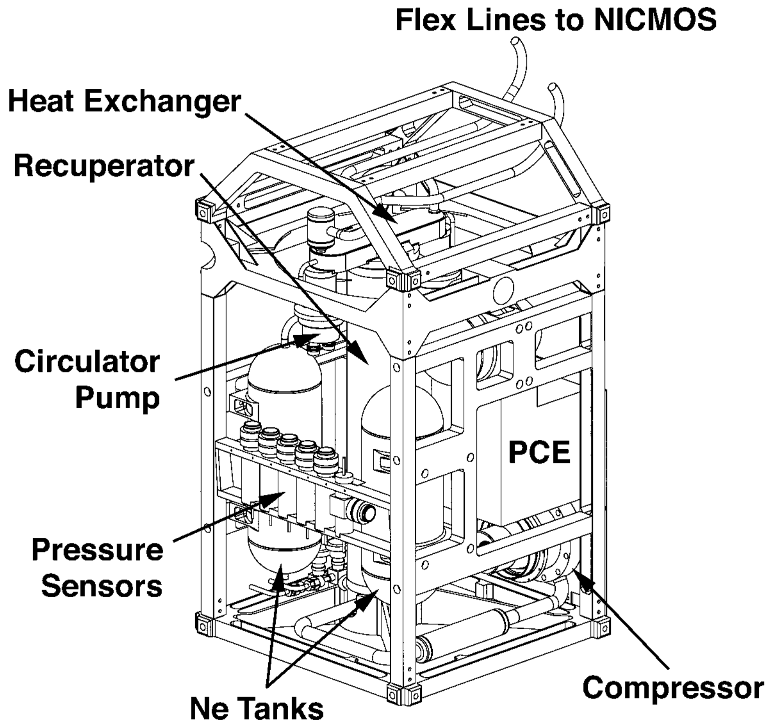

Figure 2. This figure shows the cryocooler mechanical layout. The device is about 1 meter high. The recuperator and heat exchanger areas are cold when the cooler is operating, and are covered with multi-layer insulation blankets to minimize radiation loading.

cryogenic bayonets that attach to the outside of the instrument in an astronaut-accessible design that was intended for this purpose. (Although, at the time, we were not clear on how this interface would be used.) Inside the NICMOS, the bayonets are connected to an internal cooling loop that was used for freezing the solid N_2 cryogen, and for the periodic recooling of the cryogen during ground hold.

The cryocooler is powered by the Power Conversion Electronics, which takes the main +28V supply from an astronaut accessible panel and converts it to a set of AC motor drive signals as requested by the controlling microprocessor (the Electronic Support Module, or ESM). The ESM uses a configurable control law to regulate the amount of cooling.

Sensor readings are available from critical areas in the cryocooler assembly, as well as from inside the NICMOS. These sensors are used by the control laws to control the speed of the cryocooler turbines, which in turn determine the amount of cooling.

Figure 2 shows a line drawing of the cryocooler assembly. The main components are labeled. The entire recuperator/heat exchanger assembly at the heart of the cryocooler is covered with MLI insulation to control the parasitic heat leaks from the warm parts of the assembly.

The heat exchanger is where the circulating Neon gas is cooled by the cryocooler. Circulation is forced by a turbine pump shown on the front edge of the heat exchanger.

The compressor and the Power Conversion Electronics are mounted on the rear right surface (in this diagram). This surface is the thermal interface between the major heat sources in the cryocooler (the compressor and the PCE) and the CPL which carries this heat to the external radiator.

The Neon tanks are a part of the purge and refill plumbing for the gas that will carry heat from the NICMOS. After installation of the bayonets on-orbit, we will open a set of valves that will charge the closed loop with Neon gas. The tanks also contain sufficient capacity for a full second charge in the event of slow leaks.

4. INSTALLATION IN THE HST

The availability of astronaut-accessible cryogenic interfaces on the NICMOS is the key to being able to implement the NCS concept. The interfaces on the instrument include the two cryogenic bayonet fittings (inlet and outlet), and the two in-line cryogenic valves for these access points. The mechanical configuration of the NCS in the aft shroud is shown in Figure 3. The external radiators are shown in Figure 4.

During SM3, the astronauts will first be installing the ESM on the opposite side of the HST from that which is illustrated in Figure 3. The ESM also supports the Aft Shroud Cooling System (ASCS) which is installed before the NCS. The ASCS is otherwise independent of the NCS. It contains four CPL lines connected to a separate external radiator (see Figure 4). These lines are attached by the astronauts to several locations on the other instruments in the aft shroud in order to optimize their scientific performance, generally by cooling their internal detector assemblies.

Prior to NCS installation, the covers on the NICMOS bayonets will be removed and the in-line valves opened in order to vent residual gas in the loop. The baseline procedure assumes that the cryostat will be at ambient temperature ($\sim$ 0C) by the SM3 time-frame. (We will be able to confirm this after the cryogen is depleted.) There is a small chance that some condensed materials are left in the NICMOS loop after the initial cooldown and subsequent recooling cycles, and this step minimizes the risk of contaminating the circulator loop with this material (expected to be water and N_2).

Also prior to NCS installation, the NCS external radiator will be installed and the CPL lines fed inside the aft shroud. These lines pass through special light-tight fittings designed for the two existing cryogen vent ports (one port is used for the ASCS CPL lines, and one for the NCS CPL lines).

The cryocooler is attached to the aft shroud structure with a clamp assembly. The flex lines (permanently attached to the cryocooler) are attached to the NICMOS, and the (previously installed) CPL lines are then attached

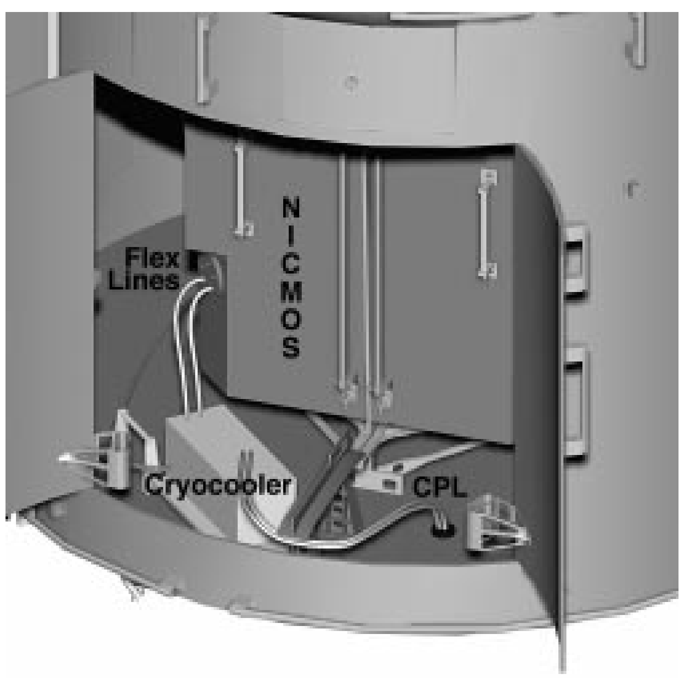

Figure 3. This figure shows the intended cryocooler location in the HST aft shroud. The flex lines carry the circulating Neon gas to and from the NICMOS. The CPL carries dissipated power from the cryocooler to the external radiator. A cable harness connects the cryocooler to the ESM, which is located on the opposite side of the HST.

Figure 4. This figure shows the location of the new radiators to be installed on HST during Servicing Mission 3 in 1999. The WFPC2 radiator is already installed on the HST (as a part of the Wide-Field and Planetary Camera 2 instrument). The aft shroud cooling system uses a similar set of CPL to cool specific areas on the other aft shroud scientific instruments.

to an interface saddle on the cryocooler. Finally, the electrical cable from the ESM is attached, and the circulator loop is filled from the Ne storage bottles on the cryocooler.

5. TESTING

Figure 5 shows a diagram of the NICMOS Cooling Loop Simulator (NCLS). The outer enclosure of the simulator emulates the temperature of the aft shroud (typically -20 C), and the inner enclosure emulates the temperature of the NICMOS enclosure (typically -10 C). The NICMOS cryostat vacuum jacket is replaced by the vacuum environment of the simulator (vacuum chamber or space). The parasitics are controlled by nylon thermal isolators and a very fine multi-layer insulation blanket.

During thermal vacuum testing, we will first characterize the parasitics of the NCLS using Helium gas flowing through the box. Inlet and outlet temperatures and the flow rate will be carefully measured, allowing us to accurately measure the parasitics that will be presented to the cryocooler as a function of external temperatures. We will use these results to validate our thermal models of the plumbing for both the NCLS and the NICMOS. We will then use the updated NICMOS thermal model to verify that the parasitic loads presented by all on-orbit conditions are acceptable.

After the NCLS parasitic loads are known, we will run a sequence of tests with the cryocooler and the NCLS. We will reject the cryocooler dissipated heat using a chilled water system instead of a radiator. These tests will verify that the proper cooldown rates are achieved by the cooler. The cooldown time for NICMOS will be estimated from the ratio of the NICMOS to NCLS thermal masses. We will also check that the cryocooler power dissipation as a function of the NCLS cold plate temperature are as expected.

Finally, an NCS system level test will verify that the cryocooler, NCLS, and CPL/radiator assemblies perform as expected. After this test, we will integrate the NCS system (together with the NCLS) into the HOST mission carrier that will bring the system to orbit during STS-95. This carrier will undergo another series of thermal-vacuum tests before being shipped to Kennedy Space Center for integration with the Space Shuttle.

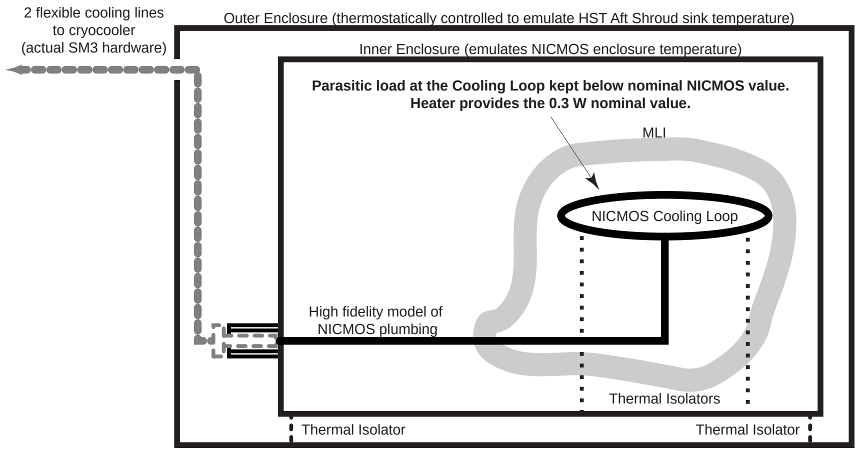

Figure 5. This figure shows the design of the NICMOS Cooling Loop Simulator. The plumbing in the loop is an exact duplicate of that in the NICMOS. NICMOS spare parts were used as much as possible to build up the cooling loop.

6. STATUS

At this time, NCLS characterization is under way, and the cryocooler is completing its final integration (see Figure 6). We expect that by early Summer, we will be completing the NCS system-level tests, and start the integration process to support the HOST mission in late 1998. All integration and test activities are proceeding as planned, with minimal schedule slippage, taking us one step closer to producing a flight qualified and tested cryocooler system in less than 1.5 years from program start.

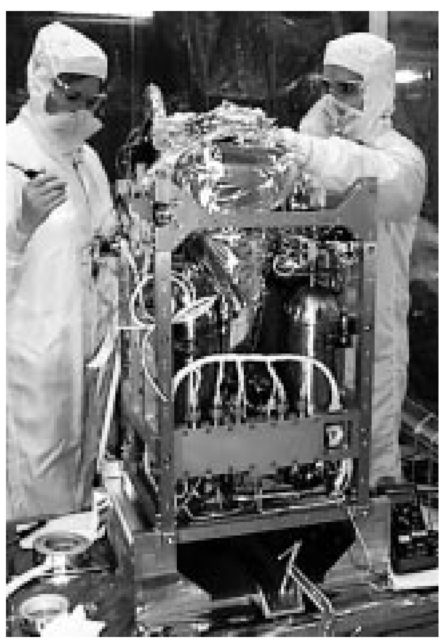

Figure 6. This photograph shows the current state of the cryocooler (early March, 1998). The MLI blankets inside the enclosure are complete and electrical tests with flight hardware have begun. Cryocooler performance tests are scheduled for late March.